DEPTH JUMP - DAMPING MECHANISM IN NON-CONTACT ACL INJURY PREVENTION

A BIOMECHANICAL EVALUATION

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ACL injury continues to be the largest single problem in orthopedic sports medicine, with approximately 95,000 new injuries occurring every year. Non-contact mechanisms represent 80% of the traumatic events resulting in more than 2000 ACL injuries per years between young athletes aged 14–23 years. Acceleration, deceleration, change of direction, landing and pivoting are the most common mechanisms responsible for non-contact ACL injuries. According to *D.A.Padua* and *S.W.Marshall (2006)*, it seems as if the most successful ACL-injury-prevention exercise programs incorporate a multifaceted exercise approach including both proprioceptive and plyometric training. Jump-landing exercises – such as the depth jump - have been used to optimize neuromuscular control of the lower extremity: damping mechanism associated with a higher degree of knee flexion – between 75 and 85 degrees - and hip flexion seems to provide the optimal muscle recruitment to improve landing technique in such activities where rapid deceleration, acceleration, pivoting and change of direction are required.

KEYWORDS: Plyometric, non-contact injury. Lower extremity injury mechanic, stretch-shortening cycle

INTRODUCTION: The International Olympic Committee (IOC) recognizes the devastating consequences of anterior cruciate ligament (ACL) injuries affecting male and female athletes; ACL injury continues to be the largest single problem in orthopedic sports medicine, with approximately 95,000 new injuries occurring every year. Non-contact mechanisms represent 80% of the traumatic events resulting in more than 2000 ACL injuries per years between young athletes aged 14–23 years. Acceleration, deceleration, change of direction, landing and pivoting are the most common mechanisms responsible for non-contact ACL injuries. Subjects who suffer ACL injury and undergo surgical intervention face a lengthy rehabilitation process ranging from 6 to 36 months, whereas only 3 out of 4 will return to their previous level of activity. Considering the high rate of incidence as well as the devastating impairment that follows the traumatic event, ACL injury can potentially hinder long term athletic development representing a major concern in terms of injury prevention strategies for both male and female athletes. Based on the reviewed research studies and case series, it seems as if the most successful ACL-injury-prevention exercise programs incorporate a multifaceted exercise approach including both proprioceptive and plyometric training. Plyometric drills – a specific form of neuromuscular training involving a reversible, explosive eccentric to concentric muscle action also known as stretch-shortening cycle (SSC) – have been shown to significantly decrease the incidence in non-contact ACL injuries especially when incorporated into a well-rounded, comprehensive strength training program. A better understanding of ACL loading mechanisms can provide an invaluable guide-line to select and implement plyometric drills as a preventive tool to reduce the incidence of non-contact ACL injury. Depth jump, the most popular plyometric exercise, will be discussed in detail.

METHOD: A systematic review of the most recent academic literature provides kinetic and kinematic data to define the proper landing technique in depth jump training. Starting from a biomechanical evaluation of the most common mechanism associated with ACL non-contact injury, depth jump training is considered in terms of initial angle of impact, overall angular displacements and final position before the takeoff. Torque and line of action of the major muscles acting directly and indirectly at the knee joint will also be considered to provide further indications.

RESULTS: From a general stand-point, the overall contributions of the muscles crossing the hip, knee and ankle joints to the total positive work done during maximal vertical jumps has been measured as follow; the average relative contributions of the ankle and hip muscles are approximately 23 and 28% respectively, with the remaining 49% of the work being done by the muscles acting at the knee joint. Above all, the initial knee angle on impact dictates the amount of external forces acting on the ACL. Any deviation of the mechanical axis of the lower extremity can create deformation of the ACL as it restrains the range of motion to counteract shear and torsional forces generated by the reciprocal movement of the femurs head upon the tibia and vice versa. ACL tensile forces increase as the knee approaches full extension and peak with knee hyperextension. At extended knee joint positions, where the patellar tendon is oriented anteriorly, the concentric action of the quadriceps muscles actively pull the tibia anteriorly: conversely, for knee angles inferior than 95 degrees – 65 degrees of flexion – the line of action of the *quadriceps femoris* shift posteriorly actively restraining the tibia from moving forward. The *quadriceps femoris'* moment arm also decreases as the range of motion increases with the largest torque generated for any given force between knee joint angles of 20 and 65 degrees. For knee joint angles smaller than 65, the hamstring forces required to balance the quadriceps action becomes larger as the knee joint reach full extension. Kinematic analysis of the knee joint in motion has provided evidence of the so-called strain-shielding effect provided by the hamstring muscles against anterior share forces acing upon the ACL: the shielding effect created by the active co-contraction of the *bicep femoris*, *semimembranosus muscle* and *semitendinosus muscle* (ACL agonists) counteract the pulling action of the knee extensors (ACL antagonists) decreasing the amount of stress place upon the ACL as the angular displacement increases above 70 degrees of flexion. Extension of the knee joint, and even more so hyperextension, associates with a violent concentric muscle action exerted by the quadriceps muscle is the primary mechanism of non-contact ACL injury in sport. Besides quadriceps and hamstrings, a set of secondary muscles located distally in respect to the knee joint are capable to affect the length and tension place upon the ACL. First and foremost the *gluteus maximus*, the strongest among the hip extensor muscles, originating from the posterior surface of the ilium. The line of action of the *gluteus maximus* can be considered in relationship to both the hip joint – directed posteriorly, approximately 45 degrees angle with respect to the frontal plane, generating both hip extension and external rotation torque - and the knee joint. In landing and pivoting movements, the eccentric contraction of the *gluteus maximus* acting on the iliotibial band counteract the internal rotation of the femurs, preventing a pattern of knee collapse where the knee falls medial to the hip and foot also known as dynamic knee valgus. Similarly to the agonist-antagonist action of the *quadriceps femoris* and the hamstrings on the sagittal plane, the shielding effect created by the active co-contraction of the *gluteus maximus* and *gluteus medius* on the horizontal-transversal plane counteract the internal rotation-valgus mechanism acting along the mechanical axis of the femur decreasing the amount of stress place upon the ACL as the angular displacement increases up until 90 degrees of flexion.

DISCUSSION: In the execution of a depth jump, the average range of initial knee flexion at impact falls between 14 and 18 degrees. The overall angular displacement of the knee joint during the amortization affects the pattern of muscle activation, ultimately dictating the magnitude, direction and orientation of the internal forces acting on the knee cap. The eccentric contraction of the muscles acting along the mechanical axis of the lower extremity partially counteract the amount of force placed upon the passive structures supporting the knee joint. The relative contribution of the ACL agonist – the *quadriceps femoris* – and antagonist – the *biceps femoris*, the *semimembranosus muscle* and the *semitendinosus muscle* – as well as the engagement of the peripheral muscle providing additional dynamic stability to the knee joint – gluts complex – dictate the sagittal and frontal deviation of the mechanical axis of the lower limb, affecting the amount of frontal shear forces and rotational forces acting on the ACL at the end of the amortization phase. In the execution of a depth jump, the average angular displacement at the knee joint during the amortization phase varies from 58 to 86 degrees of flexion. As the range of motion increases beyond 40 degrees of flexion, the ACL antagonist muscle are progressively more engaged as the action of the quadriceps muscle tends to shift posteriorly decreasing the amount of shared force acting on the tibial head. The ACL shielding effect is therefore superior with a final position before the takeoff of approximately 105 degrees of flexion on the sagittal plane. During the loading response phase of activities such as sprinting, landing and changing direction the hip flexes, adducts, and internally rotates as a consequence of the external forces acting at the joint. Excessive hip adduction and internal rotation during weight bearing activities can ultimately cause the knee joint center to move medially relative to the foot: because the foot is fixed to the ground, the inward movement of the knee joint causes the tibia to abduct and the foot to pronate, the end result being dynamic knee valgus. A correct pattern of muscle activation – in order, hip extensors, abductors, and external rotators – can counteract the amount of external forces acting upon the ACL significantly decreasing the risk of injury. Active trunk flexion, a consequence of a more significant angular displacement at the hip joint along the sagittal plane, move the ground reaction force vector anteriorly, thereby increasing the demand on the hip extensors, while simultaneously decreasing the demand on the knee extensors. *Blackburn* and *Padua* (2009) reported that landing from a jump with the trunk flexed resulted in 28% less quadriceps activation when compared to landing with the trunk more erect. Glutes and hamstring are significantly more engaged as the angle of hip flexion increases; external forces are therefore distributed along the entire posterior muscle chain, creating a more efficient pre activation of the glutes complex, the most powerful hip extensor. Dynamic knee valgus is prevented as the ratio of knee to hip flexion decreases during the amortization phase: a more efficient pattern of muscle activation during the execution of a depth jump prevents the knee from collapsing. Holcomb and al. (1997) clearly demonstrated how the execution of a depth jump is much more efficient in terms of energy reutilization when a higher degree of knee and hip flexion is achieved (Figure 1). The overall power output significantly increases when the takeoff is performed without restriction in terms of landing mechanism – 822 Watts for a higher degree of knee flexion versus 416 Watts in landing with knees close to full extension – with a much more relevant contribution of the knee joint: 482 Watts for a more pronounced damping mechanism versus with 49 Watts in the un-damped situation. The data collected by Ebben et al (2008) support the hypothesis originally proposed by Holcomb et colleagues (1997): although a relative lower activation of the muscle surrounding the knee joint during the execution of a depth jump, the higher vertical elevation reached at the end of the takeoff is symptomatic for a better utilization of the stretch-shortening mechanism during the eccentric-concentric muscle action that takes place upon landing. The amount of torque produced in the execution of the depth jump with a greater degree of knee flexion - 221 Nm at the knee joint and 255 Nm at the hips - is significantly less than the amount of torque produced during the execution of a un-damped drop rebound jump – 318 Nm at the knee joint and 369 Nm at the hips – with a relative lower activation of the contractile component of the muscle-tendon complex and a much higher reutilization of the elastic energy stored in the connective element along the kinetic chain. Less hysteresis leads to a more efficient dispersion of forces throughout the elastic component of the muscle-tendon complex ultimately decreasing the amount of tensile stress placed upon the ACL's bundles.

Damping Mechanism in Depth Jump Training
Kinetic and Kinematic Evaluation

	Join Movement		Un-Damped Mechanic	Damped Mechanic
			Knee Flexion ≤ 10 Degrees	Knee Flexion ≥10 Degrees
Eccentric	Moment (Nm)	Ankle	418 ± 97	168 ± 61
		Knee	318 ± 124	221 ± 67
		Hip	369 ± 220	255 ± 108
	% of Contribution	Ankle	28	26
		Knee	29	34
		Hip	33	40
	Work (Watt)	Ankle	-2968 ± 1038	-350 ± 161
		Knee	-1595 ± 1057	-874 ± 394
		Hip	-817 ± 902	-1200 ± 488
Concentric	Moment (Nm)	Ankle	376 ± 63	137 ± 58
		Knee	93 ± 49	206 ± 71
		Hip	471 ± 174	157 ± 76
	% of Contribution	Ankle	40	28
		Knee	10	41
		Hip	50	31
	Work (Watt)	Ankle	2468 ± 460	462 ± 210
		Knee	529 ± 306	1579 ± 2241
		Hip	1695 ± 736	684 ± 430
Total	Moment (Nm)	Ankle	392 ± 63	151 ± 59
		Knee	187 ± 61	212 ± 67
		Hip	436 ± 172	202 ± 86
	% of Contribution	Ankle	39	28
		Knee	18	38
		Hip	43	36
	Work (Watt)	Ankle	2637 ± 629	409 ± 165
		Knee	981 ± 451	1584 ± 2204
		Hip	1399 ± 655	938 ± 424

Figure 1 - Adapted from: Holcomb, W.R., Lander, J.E., Rutland, R.M., Wilson, G.D. (1996). A biomechanical analysis of the vertical jump and three modified plyometric depth jumps. *The Journal of Strength and Conditioning Research*, 10(2), 83-88.

CONCLUSION: Evidence in the most recent academic literature has shown the importance of plyometric training in non-contact ACL injury prevention protocols. Jump-landing exercises – such as the depth jump - have been used to optimize neuromuscular control of the lower extremity, improving the damping mechanism displayed in activities where rapid deceleration, acceleration, pivoting and change of direction are required. Landing with a greater degree of knee flexion significantly decreases the amount of stress placed upon the ACL. Increasing the initial knee angle on impact from 135 to 180 degrees can increase the ground impact force by 50%, approximately 1% per initial degree of knee flexion; with no restriction imposed, the proper execution of a depth jump should allow for 75 to 85 degree of angular displacement during the amortization phase, with a final position before the takeoff of approximately 105 degrees of flexion. Active trunk flexion, a consequence of a more significant angular displacement at the hip joint, also contributes to establish the correct pattern of muscle activation resulting in 28% less quadriceps activation when compared to landing with the trunk more erect. Dynamic knee valgus is prevented as the ratio of knee to hip flexion decreases during the amortization phase. A greater degree of knee and hip flexion also contribute to reduce the amount of internal forces acting upon the joints, creating a more efficient dispersion of forces throughout the elastic component of the muscle-tendon complex ultimately decreasing the amount of tensile stress placed upon the ACL's bundles. A high degree of knee and hip flexion ultimately affects the pattern of muscle activation, significantly increasing the overall efficiency of the movement: a proper landing mechanism can therefore promote short and long term adaptations in terms of both neuromuscular control and muscular development significantly decreasing the incidence of non-contact ACL injury.

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